Improvement Design of Storm Sewer Network for Flood Control

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Abstract

This study appraises the conditions of the existing drainage network of Samaru, Zaria, Nigeria, in order to identify areas constantly affected by flood on yearly basis and hence measures are put forward that will adequately cater for the incessant flood problems bothering the community. The entire catchment has been sub-divided into 13 sub-catchments from which the catchment areas, composite runoff coefficients, lengths of the farthest points to the outlets, and elevations were obtained from Google earth satellite imagery and Global Positioning System (GPS) for the computation of slopes. The parameters obtained were used as input parameters into the computer package, Flow Master and the capacities of the existing storm sewers (ESS) were computed. The peak discharge generated in each sub-catchment was computed using the rational method. Subsequently, using evaluation criteria and a scoring matrix, the system performance was evaluated and found to be about 35% efficient, hence leading to that an improvement design should be carried out. An optimized improvement design was then proposed.

Keywords

Storm Sewer; Flood Control; Improvement Design; Satellite Imagery

Introduction

Throughout the recorded history, there has been evidence that mankind has feared and respected the destruction power of water in such forms as tides and floods. Water could be destructive when in excess and in absence of adequate drainage system, and it could lead to erosion, water logging, road deterioration, flooding etc.

Storm sewers according to AISI (1999) are pipes (may be open or closed) used to collect and direct excess runoff by gravity from a given catchment in a safe, convenient and environmentally friendly manner to a treatment facility or disposal site. They are designed as open channels where there is a free water surface or pipe flow under surcharged conditions. Regardless of whether the sewer system is designed as an open channel or closed system, a thorough hydraulic analysis is required to ensure that the system operates efficiently. Storm sewers are designed to carry the surface and storm water passing through or generated in an area which they serve. Generally, urban areas in Nigeria have inadequate, improper or no drainage facilities. The study area which is a semi-urban area is an example of such areas and specifically characterized with flood-prone areas along the roads, indiscriminate disposal of wastewater from households on the streets and after-rain water pool all of which affect the socio-economic life of the inhabitants. This phenomenon is also aggravated by lack of maintenance, which subsequently leads to blockage. The drains are not properly constructed and their hierarchies are not well defined as such their capacity cannot drain storm water adequately, leading to flooding, erosion of road surfaces, reduction of accessibility to some areas and reduce aesthetic values as well as pollution and other health hazards. The major aims and objectives of this study is to appraise the condition of the existing storm sewers in order to identify areas of improvement; to provide methods of solving the problems associated with the storm drains so as to achieve self cleansing velocity even with the minimum dry weather flow; to propose an optimized improvement design of storm sewers in Samaru with the help of Flow Master.

Samaru is about 15 km north of Zaria city along the Zaria-Sokoto trunk "A" road. The settlement is directly opposite Ahmadu Bello University (A.B.U.) Main Campus. It is bounded to the East by the College of Leather and Chemical Technology (CHELTEC) and the Industrial Development Center (IDC). To the South, it is bounded by the Ahmadu Bello University (A.B.U.) Main Campus and to the North by Hayin Dogo residential area (Halifa, 2006). Samaru has the

same climatic conditions as Zaria urban region. It was found from Google earth satellite imagery that it is located at latitude 11⁰ 09′ N, longitude 07⁰ 39′E and about 671 m above mean sea level. According to Zaria master plan (2000) Samaru has an average annual rainfall of 1100 mm. Based on the universal characteristics of precipitation in arid zones, Halifa (2006) reported that the area has two distinct seasons, the wet and the dry seasons. Its period of rain is from May to October and for the rest of the year a prolonged period of dryness prevails on most of the land area.

Materials and Methods

The methodology involves the implementation of a reconnaissance survey, the purpose of which is to know the physical and hydraulic features of the project area, existing characteristics of the drains, and then assess the conditions of the existing storm sewers, identify possible areas of improvement, causes of the difficulties facing the drains, and divide the entire catchment into sub-catchment areas for easier analysis. The result of this survey formed the basis for quantifying the storm water generated per zone.

Data Analysis

The existing drain capacities was computed using FlowMaster, an easy to use software developed by Haestad Methods (2002) that deals with the hydraulic design and analysis of pipes, ditches, open channels etc. It computes flows and pressures based on well known formulae such as the Darcy-Weisbach, Hazen-Williams, Kutter's and Manning's equations. In FlowMaster, outputs for open channels include flow area, wetted perimeter, velocity, critical slope, Froude's number, top width etc. The program's flexibility allows one to choose an unknown variable then automatically computes the solution after one enters known parameters. The runoff coefficient, time of concentration, time of flow, rainfall intensity and peak discharge generated in each sub-catchment were computed using the equations below respectively:

$\mathrm{C} = \frac{\sum_1^n \mathrm{C_n A_n}}{\sum_1^n \mathrm{A_n}}$, $\mathrm{T_c} = \mathrm{T_f} + \mathrm{T_i}$, $\mathrm{T_f} = \frac{0.000138\,(\mathrm{L})^{0.77}}{\mathrm{S}^{0.385}}$, $\mathrm{I} = \frac{2667}{\mathrm{T_c}+20}$, and $\mathrm{Q} = 0.278\mathrm{CIA}$

Development of Evaluation Criteria

In order to properly appraise the existing storm sewers (ESS) adequately, evaluation criteria were developed. The key performance areas to be evaluated by these criteria are itemized below:

i. System performance
   - Adequacy
   - System capacity
   - Spatial coverage

ii. Condition of drains
   - Proneness to flooding
   - Mode of failure

iii. Operation and maintenance (O & M)
   - Maintenance planning
   - Rehabilitation
   - Maintenance responsibility

A scoring matrix was developed in accordance with each criterion using a rating scale of 0-5. Excellent = 5, Very good = 4, Good = 3, Fair = 2, Poor = 1, 0 = Not available (Akali et al. 2012a and b; Lukman et al. 2009; Lukman, 2010).

a. System performance: Here, the key performance indicators (KPIs) used are: adequacy, system capacity and spatial coverage.

b. Condition of drains: Evaluating the condition of existing drains based on proneness to flooding, possible modes of failure was carried out, which can answer questions like the capacity of the drains to contain the peak discharge and what are the possible modes of failure in the ESS.

c. Operation and maintenance (O & M): The KPIs are Maintenance planning, rehabilitation and maintenance responsibility, which is the answer to such questions like how frequent are the storm sewers maintained, rehabilitated and who is responsible for the maintenance work. A sample scoring matrix for the KPIs is presented in tables 3.1 - 3.3 below:

Improvement Design Equations for the Storm Sewers

For most economic rectangular sections:

$$V = \frac{1}{n} R^{2/3} S^{2/3} \text{ or } Q = \frac{A}{n} R^{2/3} S^{2/3}, \quad b = 2y \textit{ and } \quad y = \left(\frac{2Qn}{S^{1/2}}\right)^{3/8}$$

For most economic trapezoidal sections:

$$b = 1.15y \textit{ and } y = \left(\frac{Qn}{1.314 S^{1/2}}\right)^{3/8}$$

Results and Analysis

The capacities of the existing drains were computed using Flow Master after the dimensions were analyzed with the help of Google Earth satellite imagery. These results are shown in table 4.1 below, where

R=Rectangular sections and T* = Trapezoidal sections, S = Channel slope, Y = Channel depth, B = Bottom width and T = Top width.

TABLE 3.1 CONDITIONS OF ESS

Key Performance Indicators	Key Performance Objective	Score
Flood prone	(i) Not prone to flooding	5
	(ii)Slightly prone flooding	4
	(iii)Averagely prone to flooding	3
	(iv)Moderately prone	2
	(v)Highly prone to flooding	1
Mode of failure	(i)Collapse	5
	(ii)Erosion	4
	(iii)Blockage	3
	(iv)Cracking	2
	(v)Lack of Maintenance	1

TABLE 3.2 OPERATION AND MAINTENANCE (O & M)

Key performance indicator	Key performance Objective	Score
Maintenance planning	(i) Daily routine maintenance	5
	(ii)Weekly routine maintenance	4
	(iii) Fortnightly routine maintenance	3
	(iv) Monthly routine maintenance	2
	(v) Occasionally	1
Rehabilitation	(i) Monthly rehabilitation established	5
	(ii) Every 3 months	4
	(iii) Every 6 months	3
	(iv) Annually	2
	(v) When the need arises	1
Maintenance responsibility	(i) Community organizers	5
	(ii) Local government authority	4
	(iii) Private organization	3
	(iv) Individual household	2
	(v) No defined body	1

TABLE 3.3 SYSTEM PERFORMANCE

Key Performance Indicator	Key Performance Objective	Score
Adequacy(Conveyance of Peak flow)	(i)≥70% of Q_p	5
	(ii)60-69% of Q_p	4
	(iii)50-59% of Q_p	3
	(iv) 40-49% of Q_p	2
	(v)< 40% of Q_p	1
System Capacity Utilization	(i)Excellent	5
	(ii)Very Good	4
	(iii)Good	3
	(iv) Fair	2
	(v)Poor	1
Spatial coverage	(i)≥70%	5
	(ii)60-69%	4
	(iii)50-59%	3
	(iv) 40-49%	2
	(v)< 40%	1

TABLE 4.1 CHARACTERISTICS OF EXISTING DRAINS

DRAINS	SHAPE	**T** (**m**)	**Y** (**m**)	**B** (**m**)	L (m)	S	$Q_p m^3/s$
40-3	R	0.74	0.68	-	197.04	0.0102	1.29
8-39	R	0.70	0.61	-	414.21	0.0111	1.57
12-11	R	0.72	0.60	-	182.14	0.0549	2.88
20-19	R	0.69	0.61	-	173.53	0.0576	2.83
38-7	R	0.75	0.62	-	254.74	0.0131	2.15
37-38	R	0.78	0.70	-	390.90	0.0767	4.62
15-36	R	0.67	0.52	-	237.62	0.0842	2.69
9-8	R	0.59	0.45	-	286.00	0.0699	1.71
10-13	R	0.60	0.52	-	194.02	0.0103	0.80
13-12	T*	0.78	0.55	0.43	282.95	0.0353	1.70
15-14	T*	0.82	0.61	0.50	261.09	0.0383	2.25
18-21	R	0.45	0.28	-	178.58	0.0122	1.98
21-20	R	0.48	0.22	-	283.79	0.0106	0.20
23-22	R	0.51	0.72	-	295.26	0.0667	2.41
26-29	R	0.42	0.30	-	307.38	0.0651	0.61
29-28	R	0.54	0.69	-	347.14	0.0202	1.37
31-30	R	0.63	0.65	-	329.62	0.0121	1.23
10-11	R	0.58	0.46	-	287.54	0.0695	1.71
1-2	R	0.71	0.45	-	111.52	0.0179	1.12
3-4	R	0.73	0.42	-	112.17	0.0089	0.75
4-5	R	0.52	0.53	-	181.66	0.0110	0.69
5-6	R	0.44	0.40	-	352.54	0.0567	0.88
18-19	T*	0.82	0.53	0.46	288.67	0.0139	1.10
16-17	T*	0.75	0.62	0.48	260.75	0.0384	2.09
24-25	R	0.51	0.74	-	299.75	0.0667	2.49
26-27	R	0.46	0.28	-	290.34	0.0103	0.25
32-33	R	0.63	0.76	-	338.88	0.0118	1.47
34-35	R	0.50	0.69	-	342.55	0.0234	1.31
22-17	R	0.43	0.29	-	182.18	0.0129	1.88
25-30	R	0.45	0.69	-	295.87	0.0676	0.30
15-36	R	0.66	0.60	-	237.62	0.0842	2.69

TABLE 4.2 SUB-CATCHMENT DIVISION

SUB-CATCHMENT	AREA (m^2)	AREA (Km^2)
S_1	29,951.61	0.0298
S_2	98,557.53	0.0986
S_3	102,615.99	0.1026
S_4	54,744.40	0.0547
S_5	48,266.64	0.0483
S_6	51,374.10	0.0514
S_7	49,446.58	0.0495
S_8	131,457.35	0.1315
S_9	55,305.03	0.0553
S_{10}	88,998.73	0.0889
S_{11}	166,461.90	0.1665
S_{12}	100,433.63	0.1004
S_{13}	70,772.21	0.0708

TABLE 4.3 CALCULATION OF PEAK DISCHARGE

Sub-Area	A($\mathbf{Km^2}$)	$\mathbf{T_i}$ (hr)	$\mathbf{T_f}$ (hr)	$\mathbf{T_c}$ (hr)	I (mm/hr)	C	$\mathbf{Q_p (m^3/s)}$
$\mathbf{S_1}$	0.0298	0.167	0.101	0.268	131.59	0.51	0.56
$\mathbf{S_2}$	0.0986	0.167	0.338	0.504	130.07	0.59	2.10
$\mathbf{S_3}$	0.1026	0.167	0.222	0.390	130.80	0.72	2.69
$\mathbf{S_4}$	0.0547	0.167	0.167	0.335	131.15	0.70	1.40
$\mathbf{S_5}$	0.0483	0.167	0.162	0.329	131.19	0.68	1.20
$\mathbf{S_6}$	0.0514	0.167	0.168	0.335	131.15	0.66	1.24
$\mathbf{S_7}$	0.0495	0.167	0.186	0.353	131.04	0.66	1.19
$\mathbf{S_8}$	0.1315	0.167	0.208	0.375	130.90	0.59	2.82
$\mathbf{S_9}$	0.0553	0.167	0.168	0.167	131.15	0.69	1.39
$\mathbf{S_{10}}$	0.0889	0.167	0.178	0.345	131.09	0.39	1.26
$\mathbf{S_{11}}$	0.1665	0.167	0.154	0.321	131.25	0.55	3.34
$\mathbf{S_{12}}$	0.1004	0.167	0.184	0.351	131.05	0.76	2.78
$\mathbf{S_{13}}$	0.0708	0.167	0.180	0.347	131.08	0.45	1.16

TABLE 4.4 PERFORMANCE EVALUATION OF THE ESS

Categories	Sub-categories	Score
System Performance	(i) Adequacy	4
	(ii) System Capacity	3
	(iii) Spatial coverage	1
Condition of drains	(i) Flood prone	1
	(ii) Mode of Failure	1
Operation and Maintenance	(i) Maintenance Planning	1
	(ii) Rehabilitation	1
	(iii). Maintenance responsibility	2
TOTAL POINTS	40	14
PERCENTAGE (%)		35%

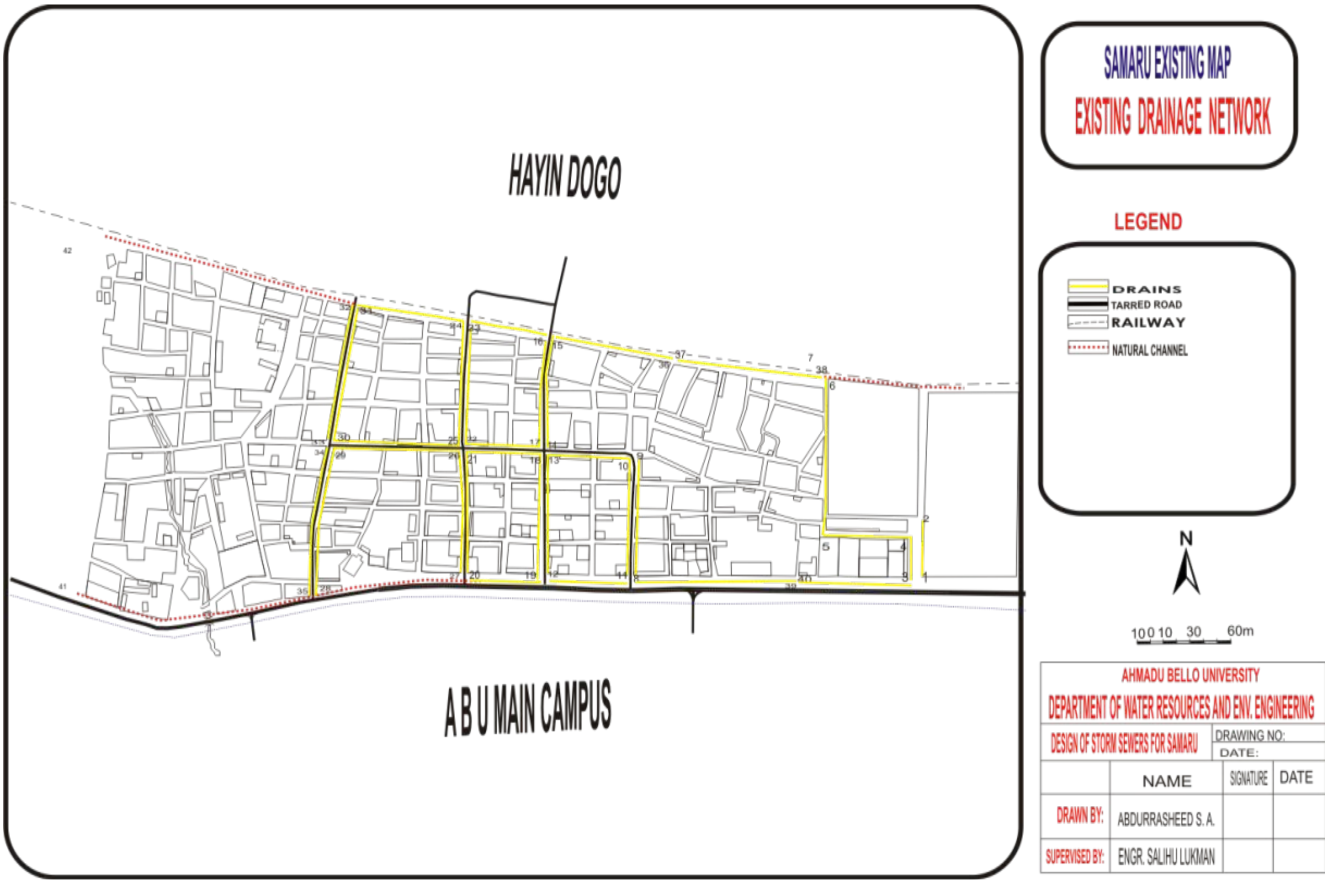

FIG. 1 EXISTING DRAINAGE NETWORK OF THE STUDY AREA

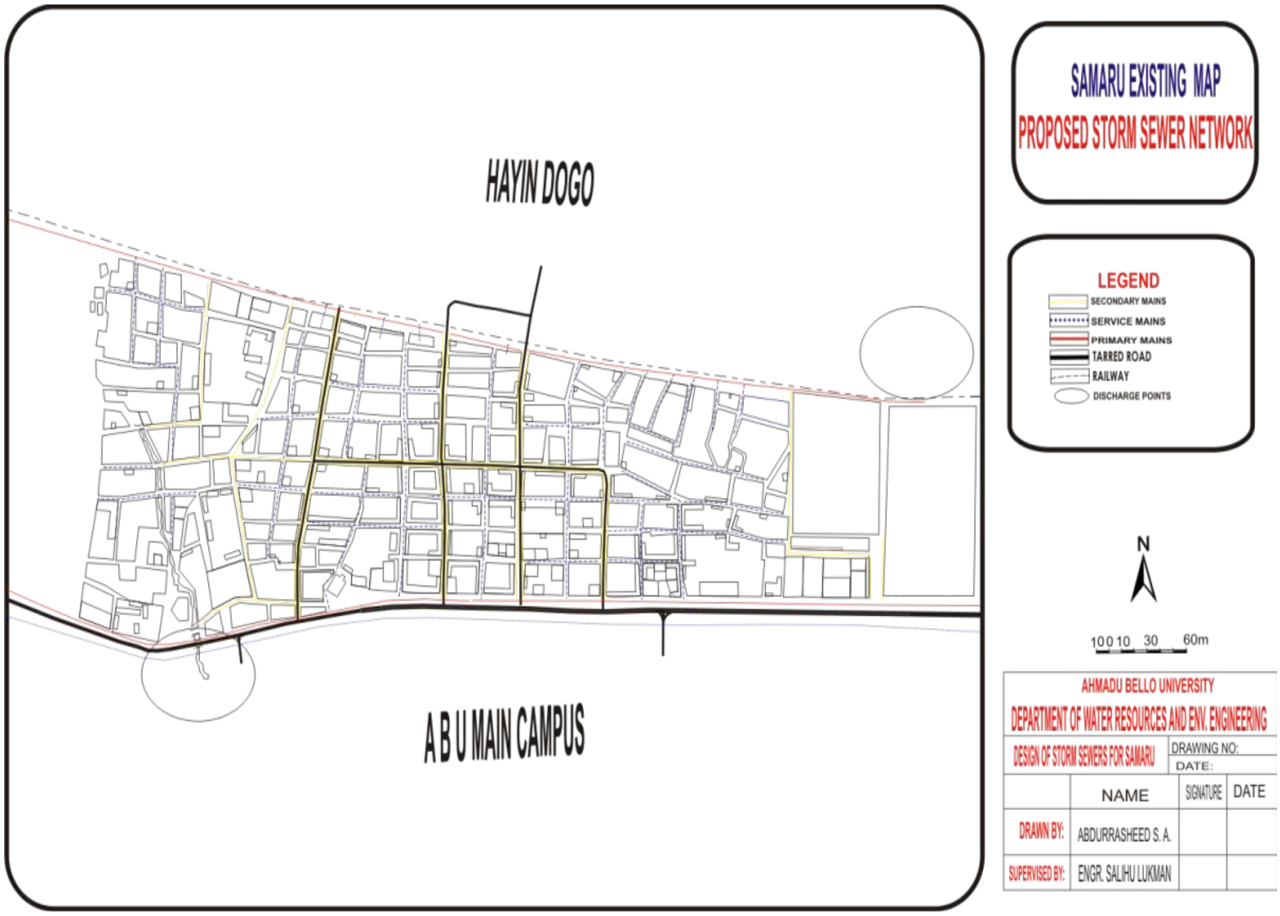

FIG. 2: PROPOSED DRAINAGE NETWORK OF THE STUDY AREA

Discussion

From the characteristics of the existing storm sewers presented in table 4.1, the peak discharge to be contained by each drain was computed using Manning's equation and from the data in table 4.2 and 4.3, the peak discharge generated in each sub-catchment was computed using rational method. Performance evaluation was then carried out using the developed evaluation criteria highlighted above and the KPIs shown in table 4.4, at the end, the overall system performance stood at 35%, which implied that the overall performance is not appreciable. This called for improvement design of the sewer network. The existing drainage network is presented in Fig. 1 while its improved version, which takes care of the drain capacity as well as discharge point to ensure flood-free sewer network is depicted in Fig. 2. During the design, a number of trapezoidal and rectangular sections were designed using the peak discharges generated and applying the design equations above. The entire catchment was sub-divided into 13 sub-catchments from which the catchment areas, composite runoff coefficients, lengths of the farthest points to the outlets, and elevations were obtained from Google earth satellite imagery and Global Positioning System (GPS) for the computation of slopes. The parameters obtained were used as input parameters into the computer package, in addition, Flow Master and the capacities of the existing storm sewers (ESS) were computed. At the end, an estimated total cost of ₦5,440,565.50 ($ 34,000) was arrived at in the bill of quantities (BOQ) which involves the costs of the general earthwork, concrete ancillaries, placing of concretes as well as culvert design.

Conclusions

From the research carried out, the followings can be deduced:

i. The major problems encountered during the study were problems of flooding, erosion and pollution of water and air from the open gutters, mostly due to inefficient drainage network, lack of continuity in drain construction, improper solid waste management, and blockage as a result of the lack of maintenance.

ii. Maintenance of the drains has been carried out wholly by individuals and this does not

ensure continuity, and there is no communal effort in the provision of drains.

iii. Samaru has no designated refuse dump sites as such, refuse is dumped indiscriminately. Waste collection is haphazardly carried out and these wastes usually end up in the drains, which results in blockage.

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